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(54) METHOD OF OPERATING A TURBOMACHINE PLANT AND PLANT FOR PERFORMING THE METHOD

(71) We, BBC BROWN BOVERI & COMPANY LIMITED, a Swiss Company of CH—5401 Baden, Switzerland, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to turbo-machine plants comprising a gas turbine, a synchronous electrical machine and a compressor plant, in which the times at which the gas turbine and the compressor plant are operative are substantially separated, for example as is the case in air accumulator-gas turbine plant. Normally, during compressor operation the gas turbine is disengaged by means of a clutch and the synchronous machine acting as a motor drives the compressor or compressors. To generate power, the compressor is or compressors are disengaged and the gas turbine drives the synchronous machine acting as a generator.

German Patent Specification No. P2355789 discloses a turbomachine plant, comprising a gas turbine, a synchronous machine adapted to operate alternatively as a motor or as a generator, and a compressor plant, in which during compressor operation the gas turbine delivers no power and the synchronous machine drives the compressor plant, and in which during the power generation the gas turbine drives the synchronous machine, the compressor plant being then changed to an operating state of low power consumption. The compressor plant is normally disengaged from the gas turbine and synchronous machine when the latter is being driven as a generator, and a clutch must therefore be provided between the compressor plant and the synchronous machine. The gas turbine drives the synchronous machine for power generation during compressor operation only in the event of an emergency i.e. if the delivery of electrical energy (the changeover to gas turbine operation) is suddenly demanded during compressor operation and the compressor plant is not disengaged. Despite the provision for changeover of the compressor plant to an operating state with a low power consumption, the compressor plant nevertheless consumes 10 to 20% of the gas turbine output when it is driven idly during current generating operation.

According to the present invention, the compressor plant remains coupled to the synchronous machine in all operating states, and during the generation of energy or current it is driven with a restricted air inlet with a power loss which is small in relation to the output of the gas turbine.

The invention also resides in a turbomachine plant comprising a synchronous electrical machine adapted to operate alternatively as a motor or a generator, a gas turbine for driving the synchronous machine, and a compressor plant permanently coupled to the synchronous machine, the compressor plant having a discharge valve on its delivery side, and a suction valve whereby the compressor plant can be driven with a restricted air inlet. Preferably the compressor plant comprises several stages or individual compressors and a non-disengageable coupling is provided between the compressor plant and the synchronous machine; a first valve is provided on the suction side of the first compressor or stage which valve can be bypassed by a bypass duct containing a second valve; at least one recirculation duct extends from a position downstream of the first compressor or stage, to the suction duct at a position between the first valve and the suction side of the first compressor or stage and contains a third valve; and a discharge valve is disposed downstream of the last compressor.

The compressor plant is no longer disengaged from the synchronous machine in generating operation, but rotates as a vacuum pump, thus dispensing with the need for a clutch between the compressor plant and the synchronous machine and enabling such a clutch to be replaced by a simple rigid coupling. In order to minimize the losses in the rotating compressor plant during generating operation, the compressor plant is driven in vacuum operation as already mentioned; this is achieved by closing the above-mentioned first valve on the suction side. When the gas turbine is started, the above-mentioned first valve on the suction

side is closed and the discharge valve is open; the second valve, in the bypass duct which bypasses the first valve, and the third valve(s) in the recirculation duct(s) are kept partially open. The third valve is or valves are closed when the nominal speed is attained.

Absolute pressures of between 0.03 to 0.005 bar, depending on the compression ratio of the plant, can be obtained upstream of the compressor blading by closure of the first valve so that the compressor plant rotates with a restricted air inlet. This means that the mass flow throughput is correspondingly reduced to between 3 and 0.5% of its normal value. The compressor power loss during generating operation depends on the charging ratio, the compression ratio of the compressor plant and the residual mechanical losses resulting from this method of operation, and is in general 0.2 to 1.8% of the gas turbine output. The invention permits very rapid changeover from compression to generating operation, and also permits the adoption of a simpler construction for the turbomachine plant because of the elimination of the multiple axial locating means and the associated construction problems normally resulting from the provision of a clutch between the compressor plant and the synchronous machine as well as between the latter and the turbine.

The invention will be further described with reference to the accompanying diagrammatic drawing, which shows a gas turbine 1 coupled through an over-running clutch 2 to a synchronous machine 3 so that the gas turbine can drive the synchronous machine. A compressor plant, comprising a low-pressure compressor 4 and a high-pressure compressor 6, is driven by the synchronous machine, through a stepdown transmission 5 if required for the production of very high compression ratios. The compressors are provided with intermediate coolers 7, 8 and an output cooler 9.

A "rigid" or "non-disengageable" coupling 10, i.e. a coupling which is fixedly joined to the associated shaft parts, is provided between the low pressure compressor 4 and the synchronous machine 3. The suction side of the compressor 4 is provided with a valve 11 which can be bypassed by means of a bypass duct 15 which contains a valve 12. A recirculation duct 16, containing a valve 13, extends from downstream of the first compressor 4 to the suction line 18 thereof at a position 17 between the valve 11 and the suction inlet of the first compressor. A discharge duct 19 with a discharge valve 14 is provided on the delivery side downstream of the second compressor 6 which in this case is the last compressor. The actual delivery duct 20 extends to an air accumulator, not shown, if the illustrated plant is an air accumulator—gas turbine plant. A non-return valve, not shown in the drawing, is incorporated into the delivery duct 20 downstream of the discharge duct 19 to prevent backflow or discharge of compressed air in the duct 20 when the discharge valve 14 is open.

The individual steps in the operation of the illustrated plant will now be described in detail:

a) When the gas turbine 1 is started for generating current, the valve 11 will be closed and the discharge valve 14 open while the bypass valve 12 and the recirculation valve 13 are kept partly open. The amount of air which enters the compressor 4 through the shaft gland and through the valves 12 and 13 prevents the well-known rotating stall effect and associated hazards to the plant while running up to speed. After the nominal speed is reached the valve 13 is closed while the bypass valve 12 remains partly open in order to supply the required minimum quantity of air to permit stable vacuum operation of the compressor plant.

b) When the plant is started for air-compression operation, the valves 11, 13 and 14 will be open and the compressor speed is raised to the nominal speed by the synchronous machine 3 operating as a motor. The valves 13 and 14 are closed when the synchronous speed is reached and air compression commences. In order to reduce the starting power it is possible to use a starting procedure similar to that described above under a). In this case, while the speed of the compressor plant 4, 6 is raised by the synchronous machine 3 to the nominal speed, the valve 11 is closed, and the discharge valve 14 is fully open, and the valves 12 and 13 are part open; the valve 11 is opened and the valves 12, 13 and 14 are closed after the synchronous speed is reached.

c) If electrical energy is demanded suddenly during compression operation, a rapid changeover to generating operation is effected by starting the gas turbine 1, closing the valve 11 and opening the valves 12 and 14.

It should be noted that the methods of operation described under b) and c), i.e. closing or opening of the valve 11 at the synchronous speed, call for precautions in the inlet part of the axial-flow compressor, such as flow equalizers, strainers, register flaps, special inlet casings, if the downstream axial blading is not to be endangered by the rotating stall effect induced by this valve.

The invention is not confined to the illustrated embodiment. Different modifications are possible more particularly with regard to the layout of the turbomachine plant. For example, a larger number of individual compressors can be provided instead of the two compressors

4 and 6, e.g. the plant could comprise a low-pressure compressor, a medium-pressure compressor and a high-pressure compressor. It should also be noted that "compressor" in this context always refers to a compressor enclosed by a casing and containing a small or large number of stages, each comprising a rotor and stator. The recirculation duct 16, in the case of a plant comprising more than two individual compressors, can extend from downstream of the second or a further compressors (for example up to the penultimate compressor), or it is possible to provide recirculation ducts extending from downstream of several compressors of the plant, for example the first to the penultimate compressor inclusive, all the said recirculation ducts being provided with valves 13 and extending to the suction line for the first compressor at a position between the valve 11 and the suction inlet into the first compressor.

In the case of a compressor in which a substantial number of stages, each comprising a rotor and stator, are combined in a common casing, a recirculation duct may extend from a position downstream of one or more stages, such duct extending inside or outside the casing to the suction duct between the valve 11 and the first suction stage of the compressor. If the compressor contains a very large number of stages it is possible for a plurality of such recirculation ducts to be provided each extending from downstream of a respective stage to the suction duct at a position between the valve 11 and the first stage and containing a valve which corresponds to the valve 13.

For large charging ratios, the clutch between the gas turbine and the synchronous machine can also be replaced by a "rigid coupling" because the respective windage losses become small under such charging conditions. This results in a further simplification and cost reduction of the plant.

WHAT WE CLAIM IS:—

1. A method of operating a turbomachine plant comprising a gas turbine, a synchronous electrical machine adapted to operate alternatively as a motor or a generator, and a compressor plant, in which in compressor operation the gas turbine does not deliver any power and the synchronous machine acting as a motor drives the compressor plant, and for power generation the gas turbine drives the synchronous machine acting as a generator, the compressor plant remaining coupled to the synchronous machine in all operating states and during power generation rotating with a restricted air inlet with a power loss which is small in relation to the output of the gas turbine.

2. A method according to claim 1, in which the gas turbine remains coupled to the synchronous machine in all operating states.

3. A turbomachine plant for operation according to the method claimed in claim 1, comprising a gas turbine, a synchronous machine adapted to operate alternatively as a generator driven by the gas turbine or as a motor, a compressor plant which comprises a plurality of stages or individual compressors, a rigid coupling being provided between the compressor plant and the synchronous machine, a first valve on the suction side of the compressor plant, which valve is bypassed by a bypass duct containing a second valve, at least one recirculation duct extending from downstream of at least one compressor or stage to a position between the first valve and the suction side of the first compressor or stage, the or each recirculation duct being provided with a third valve, and a discharge valve disposed downstream of the last compressor or stage.

4. A plant according to claim 3, in which a rigid coupling is provided between the gas turbine and the synchronous machine.

5. A method as claimed in claim 1 or 2 for operating a plant according to claim 3 or 4, in which for power-generating operation the gas turbine is started with the first valve closed and the discharge valve open, the second and third valves being partly open and the or each third valve being closed after the nominal running speed is reached.

6. A method as claimed in claim 1 or 2 for operating a plant according to claim 3 or 4, in which during starting of compression operation the first, third and discharge valves are open and the speed of the compressor plant is raised by the synchronous machine acting as a motor to nominal running speed, and the third and discharge valves are closed after the synchronous speed is reached.

7. A method as claimed in claim 1 or 2 for operating a plant according to claim 3 or 4, in which during starting for compression operation the speed of the compressor plant is raised by the synchronous machine acting as a motor to the nominal speed, with the first valve being closed, the discharge valve open and the second and third valves partly open, and after the synchronous speed is reached the first valve is opened and the other valves are closed.

8. A method as claimed in claim 1 or 2 for operating a plant according to claims 3 or 4, or as claimed in claim 5, 6 or 7, in which for rapid changeover from compression to generation operation the gas turbine is started, the first valve is closed and the second and discharge valves are opened.

9. The method according to any of claims 1, 2, and 5 to 8 when applied to an air accumulator-gas turbine plant.

10. A plant according to claim 3 or 4, being an air accumulator-gas turbine plant.

11. A turbomachine plant substantially as

herein described with reference to the accompanying drawing.

12. A method of operating a turbomachine plant, substantially as herein described with reference to the accompanying drawing.

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1 SHEET *This drawing is a reproduction of the Original on a reduced scale*